Diode-Pumped Solid-State Lasers for High-Repetition-Rate Experiments and Ultimately for Inertial Fusion Energy

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With the anticipation that the National Ignition Facility (NIF) will achieve fusion ignition early in the next century, we have considered whether solid-state laser technology can provide a future beyond the NIF. We think that solid-state laser technology can lead to high-repetition rate, high-efficiency laser drivers for future facilities, and ultimately for Inertial Fusion Energy (IFE). We have developed laser architectures in small testbeds that have the potential to be scaled to the megajoule- and megawatt-level for IFE. We envision, however, that diode-pumped solid-state lasers (DPSSLs) can play a role prior to the emergence of a fusion-based economy, for example by serving as a laser by which to perform certain plasma physics experiments requiring tens of kilojoules (same as the Nova Laser employed at LLNL today); and also to "pre-stage" experiments before they are executed on the NIF. The enormous advantage offered by DPSSL technology is that plasma physicists can have "shots-on-demand," where the rep-rate is limited by the ability to change targets and analyze data, not by the laser. At this point the front-end and the regenerative pre-amplifier of NIF are diode-pumped, based the permissible costs of diode array pump technology. We could probably say that the NIF would be a DPSSL, if diodes were more affordable today.

The nature of DPSSLs for rep-rated fusion driver systems is more complicated than simply exchanging the flashlamps for diodes, since the diodes are a fundamentally different pump technology and numerous architectural changes are called for to take full advantage of diode arrays. In particular, the quasi-coherent character of the output allows for the option of end-pumping rather than side pumping, yielding greater pumping efficiency. Furthermore, it is most advantageous to employ Yb-doped crystals instead of Nd-doped glass (i.e. $Yb:Sr_5(PO_4)F$ or Yb:S-FAP), to capture the advantage of storing the power output of the diodes in the longer-lived excited states. The single narrow absorption near 900 nm is compatible with the monochromatic output of diodes, (but would of course be prohibitively inefficient for use by flashlamps). Another technology specifically required for rep-rated performance is near-sonic gas-cooling of the laser slabs to remove heat from the large-area surfaces. The gas-cooling, together with Yb:S-FAP gain media and diode pumping, can provide a very significant first step to realizing the next generation of fusion lasers.

We are now embarking on the conceptual design, to be followed by the implementation, of a 100 Joule class DPSSL testbed, with nanosecond pulsewidth and 10 Hertz repetition rate, called the Mercury laser. The challenges of this undertaking are inspiring, potentially leading to a new technology pathway for fusion laser technology for the next century.

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